An Improved OXC Supervisory Scheme Based on Different Time-Delay Recognition

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Abstract
A supervisory scheme based on different time-delay recognition is proposed for optical cross-connects (OXCs). Besides providing actual routing information, it can detect and locate multiple faults. Additionally, the length of longest path is minimized.

1 Introduction

All-optical wavelength-division-multiplexing (WDM) networks are emerging as a future candidate to fulfill the system development requirements of high speed, data transparency, low loss and power consuming. Optical cross-connections (OXCs) are fundamental components in WDM networks. Thus, it is necessary to provide reliable surveillance technique for OXCs to reduce unexpected faults. In [1-4], several schemes have been proposed to monitor the optical paths and detect error via checking the port-to-port connection configuration registered in the cross-connect map. However, none of them can achieve the accurate multiple faults detection and location. In this paper, we propose an improved supervisory scheme to realize the precise multiple faults detection and location. Additionally, the longest path is minimized to reduce the signal distortion due to the fiber delay. In addition, this scheme can be further used in cascaded OXCs or multicast networks.

2 Previous Work

Figure 1 shows a supervisory scheme for an $N \times N$ OXC based on different time-delay recognition. Pulse source generated by optical pulse generator is split into N optical pulse streams by a 1:N splitter. Those pulses experience different delay time when being injected into different input ports, then pass through the $N \times N$ OXC and are routed to different output ports. Finally the output signals are combined together by an N:1 combiner and converted into a serial pulse stream.

Though actual routing information can be retrieved according to the output of serial pulse stream by using the scheme proposed in [1], possible duplicate pulses make it difficult to fully detect and locate the faults. The design rule of delay array in [1] is recalled as

$$\begin{aligned} i_n - i_{n-1} &= mD \\ o_n - o_{n-1} &= i_{max} \end{aligned} \tag{1}$$

Following the rule, for a 4×4 OXC, if we assign

$$\begin{aligned} [i_1 \quad i_2 \quad i_3 \quad i_4] &= [0 \quad 2 \quad 4 \quad 6] \\ [o_1 \quad o_2 \quad o_3 \quad o_4] &= [0 \quad 6 \quad 12 \quad 18] \end{aligned} \tag{2}$$

When the OXC is in following status: 1-3, 2-1, 3-4, 4-2 and if only one of 1-3 or 4-2 fails, then it is impossible to the fault. Because pulse streams through paths 1-3 and 4-2 experience the same time delay, so the same pulse patterns are obtained at the receiver side. To avoid such cases, we need to have N different pulses in pulse stream for an $N \times N$ OXC, each corresponding to one particular input-output pair.

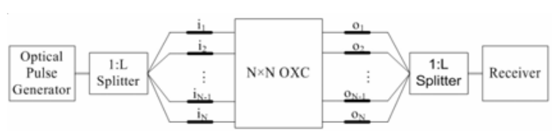

Figure 1. An $N \times N$ OXC supervisory scheme based on different time-delay recognition.

3 Proposed Supervisory Scheme

Our proposed improved scheme is based on the same structure in Figure 1. Besides retrieving the actual routing information, we want to realize precise

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faults detection and faults location by monitoring the output of serial pulse stream, and minimize the delay time for the longest path.

I	Input delay array, with dimension $N\times 1$.
i_n	Input delay at the n^{th} input port, $n\in 1{:}N$.
O	Output delay array, with dimension $N\times 1$.
o_n	Output delay at the n^{th} output port, $n\in 1{:}N$.
T	Path delay, with dimension $N\times 1$.
t_n	Path delay at the n^{th} output port, $n\in 1{:}N$.

Table 1. Notations used in the paper.

The notations used in this paper are listed in Table 1. The path delay refers to summation of input delay and output delay for a particular path.

Therefore, for an $N\times N$ OXC ($N\geq 2$), I, O and T can be represented as

$$\begin{aligned} I &= \begin{bmatrix} i_1 & i_2 & \cdots & i_N \end{bmatrix}^T \\ O &= \begin{bmatrix} o_1 & o_2 & \cdots & o_N \end{bmatrix}^T \\ T &= \begin{bmatrix} t_1 & t_2 & \cdots & t_N \end{bmatrix}^T \end{aligned} \tag{3}$$

Our objective is to find possible I and O, such that for all possible OXC connection states, the corresponding T_s are disjoint, i.e. each T corresponds to one and only one OXC connection status; and for each T, all elements t_n ($n\in 1{:}N$) are different from each other, i.e. $t_n \neq t_m$ if $n \neq m$ $(m, n \in 1{:}N)$.

Based on these requirements, it is easy to find that

$$\begin{aligned} j \neq k &\Leftrightarrow i_j \neq i_k (j,k \in 1:N) \\ m \neq n &\Leftrightarrow o_m \neq o_n (m,n \in 1:N) \end{aligned} \tag{4}$$

To avoid the duplicate pulses in the output pulse stream, the input delay array I and output delay array O for an $N\times N$ OXC are designed as:

$$\begin{aligned} I &= \begin{bmatrix} 0 & 1 & 2 & \cdots & N-1 \end{bmatrix}^T \\ O &= \begin{bmatrix} 0 & N & 2N & \cdots & (N-1)N \end{bmatrix}^T \end{aligned} \tag{5}$$

i.e.

$$\begin{aligned} i_n &= n-1\left(n \in 1:N\right) \\ o_m &= (m-1)N\left(m \in 1:N\right) \end{aligned} \tag{6}$$

Thus, the length of the longest path is N^2-1. According to the above model, the I and O of a 4×4 OXC can be designed as

$$I = \begin{bmatrix} 0 & 1 & 2 & 3 \end{bmatrix}^T \qquad O = \begin{bmatrix} 0 & 4 & 8 & 12 \end{bmatrix}^T \tag{7}$$

Table 2 shows the 4 “1” bit positions of the serial pulse stream when a 4×4 OXC is set in different connection states. The results shown in Table 2 obviously fulfill the requirements stated previously.

Case	Connection Configuration	4 “1” bit positions of the serial pulse stream
1	1-1, 2-2, 3-3, 4-4	0, 5, 10, 15
2	1-1, 2-2, 3-4, 4-3	0, 5, 11, 14
3	1-1, 2-3, 3-2, 4-4	0, 6, 9, 15
4	1-1, 2-3, 3-4, 4-2	0, 7, 9, 14
5	1-1, 2-4, 3-2, 4-3	0, 6, 11, 13
6	1-1, 2-4, 3-3, 4-2	0, 7, 10, 13
7	1-2, 2-1, 3-3, 4-4	1, 4, 10, 15
8	1-2, 2-1, 3-4, 4-3	1, 4, 11, 14
9	1-2, 2-3, 3-1, 4-4	2, 4, 9, 15
10	1-2, 2-3, 3-4, 4-1	3, 4, 9, 14
11	1-2, 2-4, 3-1, 4-3	2, 4, 11, 13
12	1-2, 2-4, 3-3, 4-1	3, 4, 10, 13
13	1-3, 2-1, 3-2, 4-4	1, 6, 8, 15
14	1-3, 2-1, 3-4, 4-2	1, 7, 8, 14
15	1-3, 2-2, 3-1, 4-4	2, 5, 8, 15
16	1-3, 2-2, 3-4, 4-1	3, 5, 8, 14
17	1-3, 2-4, 3-1, 4-2	2, 7, 8, 13
18	1-3, 2-4, 3-2, 4-1	3, 6, 8, 13
19	1-4, 2-1, 3-2, 4-3	1, 6, 11, 12
20	1-4, 2-1, 3-3, 4-2	1, 7, 10, 12
21	1-4, 2-2, 3-1, 4-3	2, 5, 11, 12
22	1-4, 2-2, 3-3, 4-1	3, 5, 10, 12
23	1-4, 2-3, 3-1, 4-2	2, 7, 9, 12
24	1-4, 2-3, 3-2, 4-1	3, 6, 9, 12

Table 2. The output pulse streams for different statuses of the proposed scheme for a 4×4 OXC.

4 Discussion

We first prove the model can realize retrieving actual routing information, faults detection and faults location. All possible spacing between any two input ports are 1, 2, …, N-1, while for any two output ports are N, $2N$, …, (N-1)N. As

$$i_0 + o_n \le t_n \le i_N + o_n \Rightarrow (n-1)N \le t_n \le nN-1 \quad (8)$$

for $m>n$ $(m, n \in 1{:}N)$, $t_m > t_n$, i.e. for a particular T, t_n is monotonic increasing with respect to n. Based on above analysis, duplicate pulses will not appear and our objectives can be achieved.

Next, to prove that the length of longest path is minimized, all possible input-output pairs are considered. As $n \in 1{:}N$, there are total N^2 input-output pairs. Thus, N^2-1 is the minimal length of the longest path, theoretically. From (5), it can be found that $t_0 = i_0 + o_0 = 0$ and $t_N = i_N + o_N = N^2-1$ are the minimum and maximum of t_n, respectively. The value of t_n is evenly distributed in the range from 0 to N^2-1. Thus, it can be concluded that N^2-1 is the minimal length of the longest path.

As in a particular T, $t_n \ne t_m$ if $n \ne m$ $(m, n \in 1{:}N)$, there are N pulses in the output pulse stream if no fault occurs. If one fault occurs, no matter the fault occurs at the input/output port or the connection in the OXC, there are only N-1 pulses in the output pulse stream. Therefore, the input-output pair which the fault occurs can be figured out and the actual routing information can be retrieved.

If more than one faults occur, as each value of t_n is corresponding to a unique input-output pair, the possible connection states can be found out through the remaining pulses in the pulse stream. The related ports which faults occur still can be tracked. Additionally, according to this one-to-one mapping feature, this scheme can also be used in multicast or broadcast networks. The actual routing information, faults detection and faults location can also be retrieved.

Furthermore, this scheme is demonstrated in cascaded OXCs. I_n and O_n are used to denote the input delay array and output delay array of the n^{th} OXC respectively. The array assignment of cascade OXCs can be expressed as follows:

For the first OXC,

$$\begin{aligned} I_1 &= \begin{bmatrix} 0 & 1 & 2 & \cdots & N-1 \end{bmatrix}^T \\ O_1 &= \begin{bmatrix} 0 & N & 2N & \cdots & (N-1)N \end{bmatrix}^T \end{aligned} \quad (9)$$

For the n^{th} OXCs (n>1),

$$\begin{aligned} I_n &= \begin{bmatrix} 0 & 0 & 0 & \cdots & 0 \end{bmatrix}^T \\ O_n &= \begin{bmatrix} 0 & N^n & 2N^n & \cdots & (N-1)N^n \end{bmatrix}^T \end{aligned} \quad (10)$$

As the spacing of elements in T ranges from 1 to N^2-1, the spacing between different elements in O_2 should be at least N^2 to avoid duplicate pulses at the output pulse stream. Similarly, for the n^{th} OXC, the minimal spacing between different elements of O_n is N^n.

Figure 2 shows an example of two cascade $N \times N$ OXCs by using above I_s and O_s assignment.

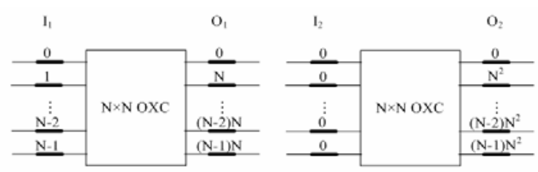

Figure 2. An example of two cascaded $N \times N$ OXCs.

5 Conclusion

In this paper, a greatly enhanced OXC supervisory scheme based on different time-delay recognition is proposed. The delay time of the longest path is minimized to reduce the distortion and complexity caused by the various fiber delay. This is crucial when the port number is large as the minimum longest path is still N^2-1. Using this scheme, the actual routing information can be retrieved, and multiple faults can be detected and located. This scheme can also be used in the broadcast and multicast networks or cascaded OXCs. The work was supported in part by a research grant from Hong Kong Research Grants Council under Project 411005.

6 References

1 C. C. Lee, et al., IEEE PTL, Vol. 17, No. 12, pp.2745-2747, Dec. 2005

2 C. K. Chan, et al., IEEE PTL, Vol. 10, pp.899-901, Jun. 1998

3 E. Kong, et al., Electron. Lett., Vol. 35, pp. 1481-1483, Aug. 1999

4 H. Li, et al.,Electron. Lett., Vol. 34, pp. 2149-2151, Oct. 1998